**Regionalization of the C-17A Home Station Check to Minimize Costs**

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## Abstract

The Department of Defense is currently dealing with the effects of sequestration and facing an uncertain budgetary future. Senior leaders face tough challenges in deciding where cuts should be made to maximize savings to preserve programs and readiness. Within this environment, the United States Air Force must seize opportunities to find cost savings and efficiency, without decreasing mission effectiveness. This research studies the C-17A Home Station Check, a mandatory maintenance requirement for every C-17 in the USAF fleet, and uses a cost minimization methodology to systematically identify potential regionalization or consolidation options. This study identifies and quantifies the major costs associated with conducting C-17 HSCs, and it examines regionalization options using a mathematical programming model to minimize the total cyclical cost of operations. Based on the analysis, several options to consolidate maintenance on fewer facilities are recommended for consideration that can save from 6.6% up to 12.4% over current C-17 HSC operations.

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Jonathan H. Magill

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REGIONALIZATION OF THE C-17A HOME STATION CHECK TO MINIMIZE COSTS

# I. Introduction

## Background

Currently, all USAF C-17s require a Home Station Check (HSC) every 120 days over a 720-day cycle. These HSCs are conducted, as the name suggests, at the individual aircraft's home station 3 times per year, with differing focus areas for each of the six scheduled HSCs. There are currently 15 Mobility Air Forces (MAF) C-17 bases with 222 C-17s assigned, consisting of 178 USAF, 26 Air National Guard (ANG), and 18 Air Force Reserve Component (AFRC) aircraft (Dorsch, 2014). Each of these bases has at least one dedicated hangar for C-17 HSCs. The two largest C-17 bases average 3 HSCs per week, while the smaller C-17 bases, including AFRC and ANG, average 3 HSCs per month. C-17s undergoing HSC maintenance are removed from the flying rotation for an average of five days before returning to flight operations.

## Problem Statement

With budgetary constraints and cost-saving measures being implemented throughout the Department of Defense (DOD), any potential areas that could save money or resources should be investigated. With 15 bases each performing the same checks on their own aircraft, it is possible that regionalization or consolidation of the C-17 HSC to a lesser number of bases could save time and resources, and possibly, cost. As a benchmark, most of the commercial airline industry limits major scheduled maintenance on their aircraft to a central location or locations. This hub and spoke method may not

work as smoothly when applied to the C-17 fleet, but this research paper will examine whether regionalization is possible and/or economically advantageous, and make a recommendation on whether it is a viable option for the fleet by investigating both pros and cons of C-17 HSC regionalization, including associated savings and costs, loss of maintenance flexibility, and impact to combat operations. The goal of this research is to provide an analysis to determine if there are benefits to C-17 HSC regionalization, whether they outweigh potential costs, and also provide recommendations to Air Mobility Command (AMC) leadership for further analysis.

**Research Focus**

The focus of this research is to analyze the C-17 HSC program and compare it to a civilian aviation model, while accurately identifing costs directly and indirectly associated with the current process. Second, the research will study the potential regionalization of HSCs and determine if any monetary savings and/or added efficiency exists by minimizing HSC redundancy at active duty bases. Inherent with HSC regionalization under the current basing model, it would be necessary to shuttle aircraft to the selected HSC bases, incurring additional flight hour and crew manpower costs. This may outweigh any potential cost benefits. Finally, if savings exist, this paper will make recommendations on how to implement a regionalized C-17 HSC program, including recommending the best base locations by analyzing whether sufficient ramp space, hangar space, equipment, etc. exist in those locations, and how logistics manpower would be affected. Finally, this research will also study if any other logistical requirements are needed at the proposed HSC bases and their associated costs.

**Research Objectives/Questions/Hypotheses**

The research objective of this paper is not simply to determine if regionalized C-17 HSCs are possible, but to analyze whether regionalization is an effective cost and resource savings alternative to the current operations. If regionalization proves to be more effective than the current process, then this research will recommend bases and logistical requirements to implement a regionalized HSC system. Several questions will need to be answered in order for this research to be effective including (but not limited to):

1. Will a regionalized C-17 HSC program provide the USAF with cost savings and increased efficiencies? If so, how many bases should be selected and where should they be located?

2. Are there any opportunities to benchmark similar programs from commercial aviation, sister services, or even other USAF aircraft?

3. Is it possible to increase HSC capacity at a given base without any new ramp or hangar construction by increasing throughput and personnel or repurposing an existing hangar as an additional dedicated C-17 hangar?

4. If cost savings are shown to exist, is HSC regionalization a good idea, how could it be implemented, and are there any areas of further study required?

**Methodology**

There are five major steps in this research to analyze C-17 HSC regionalization. First, this research will focus on collecting background information on both commercial and military maintenance practices and compare them to C-17 HSC practices. This includes studying the number of personnel, time and equipment requirements, and any other logistical necessities. Furthermore, the research will determine if any unique maintenance or logistics specific data is required at any of the C-17 bases to establish if any unusual requirements or practices exist.

Second, the research will collect data on the physical attributes of each base, determining HSC capacity based on ramp and hangar space. This step will establish current, potential, and maximum HSC capacity, independent of personnel requirements.

Third, the research will develop and analyze the costs associated with the regionalization. This includes flying hour costs to ferry aircraft, crew TDY costs, and personnel and equipment costs. To determine baseline maintainer requirements, the research will draw on authorized personnel numbers and estimate additional requirements as C-17s are added to their HSC schedule based on the ratios provided by AMC.

Fourth, this research will produce a mixed-integer linear programming (MILP) model designed to minimize costs based on user-defined inputs. This MILP will take the cost and personnel inputs defined in step three and minimize costs of the C-17 HSC. This model will be run multiple times with differing assumptions to provide AMC leadership various options with estimated costs to choose from.

Finally, based on the results of the MILP modeling, this research will recommend two potential courses of action to AMC and recommend areas of further study in order to provide more resolution to the modeling. The end-state goal is to provide all possible information in the scope of this research, backed up with MILP modeling, to develop an implementation plan in conjunction with AMC/A4.

**Assumptions/Limitations**

Due to the large scope of this problem, the research will make certain assumptions to limit the scope. Perhaps the most important of these will be limiting the research and recommendations to active duty bases and aircraft only. As previously mentioned, there

are a total of 15 C-17 bases, but only 8 are active duty. While it may ultimately make sense to also include ANG and AFRC bases in a regionalization plan, the costs and politics of moving these jobs to another state is beyond the scope of this research.

Furthermore, assumptions will have to be made regarding personnel costs. Currently, maintenance personnel do not only complete HSCs, they also complete various other duties on the airfield. By removing HSCs completely from one base and giving them to another, it is not a simple one-for-one personnel swap. Some of the HSC maintenance personnel identified in the cost analysis will still be required at the non-HSC base to conduct other maintenance duties.

This research will also make the assumption that a dedicated hanger is necessary for each C-17 HSC, although depending on the type of HSC and weather conditions it could be possible to complete on the ramp. Due to the unpredictable nature of the weather/winds and the added complexity of scheduling hangar-required HSCs versus non hanger-required HSCs, this assumption is necessary.

Finally, the research will assume that no new military funded construction will be possible due to the current fiscal environment. Therefore, only existing airfield structures with the proper requirements will be considered in the analysis, defined as a fully-enclosed C-17 capable hangar.

**Benefits/Implications of the Research**

Headquarters AMC has expressed interest in the potential regionalization of the C-17 HSC, and requested research on the feasibility and potential cost savings. This research will hopefully be the first step towards determining whether regionalization

makes sense and what are the best bases to select, if warranted. Whether or not the data proves that regionalization saves money and resources, this research will allow senior leadership to make an informed decision on the C-17 HSC process and may open the opportunity for further research to determine a better model for C-17 maintenance and management.

## II. Literature Review

### Chapter Overview

This chapter will first compare commercial versus military maintenance terminology, and define the different types of aircraft checks. After this baseline discussion, the chapter will present background information on the C-17 Home Station Check, and discuss its various requirements and how it is accomplished at each base. Finally, the chapter will look at various best practices from the commercial aviation industry and compare it with several current and proposed practices in the military community.

### Commercial Background

Aircraft inspection processes in commercial and military aviation, while often having different terminology, are very similar in practice. However, because of the differences in terminology, comparison between the commercial and military sectors often causes confusion. Typically, required commercial checks on aircraft are referred to as A, B, C, or D checks; where A and B checks are considered lighter checks and C and D checks are considered heavier and more time intensive checks. Commercial carriers also divide their maintenance into two major segments: line (consisting of gate and turnaround) and base maintenance.

Line maintenance is the minor maintenance conducted by commercial carriers at the thousands of airfields they operate from around the world each day. As a subset of line maintenance, gate maintenance is conducted in the approximately 30-60 minutes prior to each departure to ensure the airworthiness of the aircraft and only the “most

essential tasks are performed" (Choo, 2004). Turnaround maintenance, another subset of line maintenance, is usually conducted at the end location of an aircraft's schedule, typically every 3-5 days and "includes servicing, repair, and MEL deferrals" (Choo, 2004). This turnaround maintenance is also known as an A-check.

B-checks are conducted "every 3-4 months, and include both A-check activities and preventative maintenance inspections such as spectral analysis of engine fluids, filter checks, and parts lubrication" (Johnson, Heiman, Cooper, & Hill, 2010). A typical B-check will be completed within 1-3 days and normally requires an airport hangar. B-checks can fall under line or base maintenance depending on the items that are scheduled to be completed during the inspection and the type of aircraft itself.

C-checks include "detailed inspections of the airframe, engines, and accessories" and are conducted every 15-16 months, require a hangar at a maintenance base, and often take more than a week to complete (Johnson, Heiman, Cooper, & Hill, 2010).

Finally, D-checks are the most comprehensive check for an airplane. D-checks occur approximately every five years and take the entire aircraft apart for overhaul or modification. These checks are designed "to restore the aircraft to as 'new' a condition as deemed practical," may take several months to complete, and are planned by the airlines years in advance (Johnson, Heiman, Cooper, & Hill, 2010).

Heavier maintenance checks, specifically the C and D checks, in the commercial industry can be very expensive, and there has been a significant migration toward centralized maintenance processes to preserve aircraft readiness at lower cost.

## C-17 Home Station Check Background

The C-17 HSC falls somewhere between a B check and a C check on the commercial scale (Dorsch, 2014). The C-17 requires six different HSCs over its 720-day cycle, some of which are closer to C-checks and others more similar to B-checks. The HSC specifics will be described in this section.

Currently each active duty C-17 base completes HSCs on only their assigned aircraft. Each base has a different number of personnel assigned to HSCs based on how many Primary Assigned Aircraft (PAA) the base has. Most HSC personnel are also used in other maintenance functions. In other words, the manpower ratio is based on PAA, but those assigned bodies are not only completing HSCs. Each base is authorized a certain number of maintenance personnel for HSCs based on PAA as shown in Table 1, but they are used in other places when not being used in HSC.

As previously discussed, each C-17 will require one HSC every 120 days. Therefore, each C-17 assigned to each base will cycle through the HSC process once every 120 days, or 3 times per year. The average time to complete the HSC varies by base along with the management of shiftwork, but averages three to five days. The specifics for each active duty base are described in the following paragraphs.

**Table 1: HSC Authorized Manning by Base**

| | Total C-17s | Total Auth'd per PAA | Total Auth'd HSC Pers |
|---|---|---|---|
| **McChord** | 53 | 2.5 | 133 |
| **Travis** | 13 | 5.0 | 65 |
| **Hickam** | 9 | 7.0 | 63 |
| **Elmo** | 9 | 7.0 | 63 |
| **Altus*** | 17 | 5.0 | 85 |
| **Charleston** | 52 | 2.5 | 130 |
| **Dover** | 13 | 5.0 | 65 |
| **McGuire**** | 13 | 5.0 | 65 |

*Civilian Contract Maintenance

**Approx 50% of HSC Personnel dual qualified on both C-17 and KC-10

### *Scheduling*

At the majority of the bases a typical HSC is scheduled from late Sunday evening or Monday morning through Thursday or Friday, setting up a 4- or 5-day-on, 2-day-off schedule with three 8-hour shifts per day. One notable exception is Travis which runs two 12-hour shifts, setting up a 4-day-on, 3-day-off schedule. Another exception at McGuire is the Electronic and Environmental (ELEN) and Hydraulic (HYDR) systems airmen work one 8-hour shift per day, but have the flexibility to surge to one 12-hour shift per day, if required. Another notable anomaly, Joint Base McGuire-Dix-Lakehurst (JB MDL) has the only maintenance Airmen who are dual qualified on HSCs. This means that of the 40 Airmen assigned to C-17 HSCs at JB MDL there are approximately 50% who are dual qualified on both the C-17 and KC-10, which is also based at JB MDL.

C-17s are scheduled for an HSC every 120 days. Maintenance works with the Wing barrel to schedule aircraft to be available during the HSC week. If for some reason the aircraft is broken off-station, a maintenance team will travel TDY to fix the aircraft and bring it back to home station. If the aircraft is overdue for an HSC it would be grounded (i.e., not cleared to fly) and require a Major Command (MAJCOM) waiver to authorize a one-time flight to its home station.

Prior to accepting the aircraft into HSC, a negotiation process takes place to determine which delayed discrepancies, TCTOs, special inspections, and one-time inspections will be completed during the HSC. Before starting the HSC, maintenance signs a pre-HSC agreement (pre-dock contract), essentially a contract accepting the aircraft, and listing specifically what is going to be fixed on the aircraft in addition to the aircraft's respective HSC work cards and requirements. On average, a C-17 enters an

HSC with 125 write-ups in addition to the normally scheduled HSC work. These write-ups range from minor discrepancies with communications equipment or seats to relatively major fuel or electronic problems. Maintenance personnel from throughout the Maintenance Group will be assigned to work the HSC based on the overall number of personnel earned for the number of PAA. Some personnel that are not often used for HSC can be assigned by the group commander to other flights or areas and called in to work HSCs only when required, which makes it difficult to talk precise manning numbers regarding HSCs. Additionally, as part of the process most bases complete an aircraft wash and lube prior to, or following the HSC.

***Equipment Requirements***

There are only a few specific equipment requirements for a C-17 HSC. These are a Genie scissor lift or comparable stand, a "bomb loader" and engine trailer if the Auxiliary Power Unit (APU) or engines need to be removed, and potentially a high lift truck or tail stand, which every C-17 base has currently. If HSCs are conducted simultaneously then an additional tail stand may be required if work on the tail is required. All C-17 bases currently have the required equipment; therefore a regionalization would not require any new equipment purchases.

***Ramp and Hangar Space***

Each base has enough ramp space for currently assigned aircraft, however, determining available ramp space for additional transient aircraft is dependent on a number of factors that are not completely predictable. For example, available ramp space may decrease at McChord due to a C-17 and C-130 multi-lateral exercise with the Army. At Dover, extra ramp space may be unavailable due to a contingency operation or several

broken aircraft. However, any regionalized HSC plan would have aircraft scheduled for specific weeks so that available space could be forecasted with a higher degree of accuracy. In the following section, available capacity at each base will be defined, but in each case, this research determined that hangar capacity was the limiting factor.

Each C-17 HSC has different scheduled requirements, and some of the inspections are easier to complete outdoors on a ramp, while others require an enclosed C-17 capable hangar. In any case, bad weather, including high winds at or above 20 mph, would drive any HSC to be conducted in a hangar. For example, according to Lt Col Paul Filcek, deputy commander of the 60 MSG at Travis, "based on almost ten years of data, 01 Jan 2000 to 26 Aug 2010, the peak winds [at Travis] were between 20 and 39 mph on 63.4% of the days" (Filcek, 2014). Thus, Travis requires the use of hangars for tasks that could normally be performed on the line.

**Previous Commercial Research**

The individual Major Commands (MAJCOMS) are certainly faced with some pressure regarding money and resources, and there is some competition for scarce resources between other departments and services. However, unlike the Department of Defense, private sector organizations are continually faced with competitive pressure from other similar organizations and must continue to improve and innovate or lose market share. The aviation maintenance industry is no exception, and is important to benchmark for this research.

The inherent competitive nature of the private sector drives individual firms to develop strategies to optimize operations and lower costs. A thorough study of available

commercial research may uncover some useful strategies that the Air Force could adopt for the C-17 HSC process to maximize efficiency and reduce costs.

In the commercial airline and cargo industry, consolidation of maintenance, repair, and overhaul (MRO) facilities is seen as a competitive necessity. Commercial airlines have the choice between in-house maintenance and outsourcing their maintenance to a third party. Generally, low fare carriers have avoided investing in large maintenance organizations and choose to outsource to independent or other airline third party maintenance providers. According to Cohen and Wille, "the sharp competition…has forced legacy airlines either to follow this trend by outsourcing their maintenance, or to improve efficiency of their internally operated MRO organization. [T]he share of outsourced heavy airframe maintenance stands at 45% in the US and 29% in Europe, and is growing" (Cohen & Wille, 2006). Currently, only the largest commercial companies can afford in-house maintenance due to economies of scale, while smaller, low cost airlines outsource almost all maintenance to reduce total operating costs. However, outsourcing affects availability due to added transportation requirements and coordination challenges with schedules.

One of the major benefits of commercial in-house maintenance, is that "maintenance and operations can be better integrated, ensuring a smoother flow" (Choo, 2004). The commercial airline industry does not assign a company's aircraft to one particular home station, unlike the military; however, the aircraft do come back to their regionalized hubs for mx. Aircraft are scheduled to fly routes that maximize profitability and flow through the system where they are needed. Obviously, the military does not schedule or operate missions like airlines in all circumstances, however, some similar

practices may still exist. In both the commercial and military maintenance worlds, the better the operations-maintenance integration, the easier it is to schedule maintenance for individual aircraft.

Virtually all major scheduled, or base, maintenance takes place at regionalized MRO hubs when the aircraft is removed from the flying schedule (Choo, 2004). For example, the vast majority of all maintenance for American Airlines takes place at a facility in Tulsa, OK named AA-MRO. This facility has the capability to handle all the various aircraft that the airline flies, and also offers its services to other airlines and aircraft operators. According to an article in Aviation Week, “commercial carriers must seek new partnerships with MRO operators…to improve efficiencies and cut costs…[and] help them establish a realistic cost stream for the future” (Phillips, 2005). American’s Tulsa MRO overhauls and repairs over 25,000 wheels and 5,300 brakes each year--100% of the worn wheels and brakes from its fleet (Kern, 2011). This consolidated facility ensures efficient high-volume operations by focusing 100% of the work in a single shop.

When comparing commercial base maintenance at MROs and C-17 HSCs it is important to remember that there are some similarities, but also many differences. First, the Air Force already uses depot-level maintenance facilities to perform major overhauls and modifications on aircraft. For the C-17 this is normally referred to as Global Reach Improvement Program (GRIP), and is similar to a commercial D check. During GRIP the aircraft normally undergoes block upgrades or other major equipment upgrades or overhauls. Typically, the GRIP or depot process for military aircraft is extremely in depth due to the unusual stress that military operations place on our aircraft. These depots tend

to operate much more similar to commercial MROs. Depots will be further discussed in the following section. Second, MROs tend to service more than one type of aircraft or focus on one type of aircraft component, for example engines, so that they can maximize business opportunities. Consolidated C-17 HSCs would not be designed to do this. However, there are several good lessons that MROs provide when we look at potential gained efficiencies.

## Differences in Depot Level Maintenance

Instead of two levels of maintenance like the commercial industry, the military previously used three: line or organizational level, intermediate level, and depot level. Flight line and turnaround maintenance performed prior to or after each flight is similar to commercial line maintenance. The term intermediate level maintenance is no longer used in the MAF, since intermediate level maintenance is almost always completed at the organizational level. However, for clarity, this research will use the term intermediate level for ease of understanding the HSC regionalization argument.

Therefore, intermediate level maintenance includes “both off-equipment component repair and on-equipment aircraft inspections” and isochronal inspections which are based on the elapsed time interval since the last inspection (Tripp, McGarvey, Van Roo, Masters, & Sollinger, 2010). Based on this definition, C-17 HSCs fall under isochronal intermediate level maintenance. As discussed previously, all HSCs are currently completed at each aircraft’s home base, unlike the commercial model, every 120 days. Only when intermediate maintenance is incapable of more demanding repairs,

or when the aircraft is scheduled for significant upgrades, overhaul, or modification will it be sent to depot level maintenance.

Depot level maintenance for the C-17 is conducted at Warner-Robins AFB, GA and the Boeing Support Service Center (BSFC) in San Antonio, TX. Therefore, in effect, depot level (D-check equivilient maintenance) has already been regionalized by the Air Force. Although Boeing holds the contract for depot level C-17 maintenance, U.S. government regulations require the Air Force to maintain at least 50% of the workload for threat mitigation and readiness. Therefore, Boeing contracts 50% of the depot level checks back to Warner-Robins Air Logistics Complex government personnel.

The regionalized C-17 HSC plan would not be "depot level" maintenance. If regionalized, the C-17 HSC process would be virtually identical to the current process conducted at every base, however would not fit the definition of organizational level maintenance, hence the decision to use the term intermediate level to describe the regionalized HSC. Furthermore, the military would be using consolidated in-house maintenance in order to maintain control of the process and maximize operations-maintenance coordination. The following sections will focus on previous DOD based research and plans dealing with similar inspection regionalization to both set a baseline for how a C-17 regionalized HSC program could work.

**Previous DOD Research**

In 2010, the RAND Corporation released a report sponsored by the U.S. Air Force that among other things, looked at "consolidating certain scheduled maintenance tasks…at centralized repair facilities" for the C-130, KC-135, and the F-16 (Tripp,

McGarvey, Van Roo, Masters, & Sollinger, 2010). The research focused on finding more efficient ways to support continuous aircraft deployments with fewer people while still maintaining the same or better level of aircraft availability. While the research did not look at C-17 HSCs, many of the findings are still applicable and worth incorporating in this research.

The RAND researchers reasoned that consolidated facilities would be more efficient due to labor economies of scale which would allow larger maintenance operations to use personnel more efficiently. According to the report, “smaller, decentralized maintenance operations have relatively low personnel utilization for two reasons.” The first is minimum-crew size effects, “which occur because the work center task that demands the most crew to perform determines the minimum crew that can be assigned to the facility.” The second reason is insurance effects that allow a maintenance organization to accommodate random spikes in demand, or surge, without too great an effect on flying operations.

As previously established, maintenance personnel at each base are determined by number of PAA. Elmendorf and Hickam, both Pacific Air Forces (PACAF) bases, have the fewest C-17s at nine each. Therefore, these two bases have the smallest number of active-duty C-17 HSC authorized personnel based on the ratio provided by AMC. Travis, McGuire and Dover each have thirteen assigned C-17s, and McChord and Charleston have 53 and 52 PAA, respectively.

Altus, with 17 assigned aircraft is the exception. Since Altus is all civilian maintenance (no military workers), their maintainence manning does not fit the AMC ratio. Altus is considered a Most-Efficient-Organization (MEO) and is paid an amount to

complete a certain number of HSCs. If the Air Force needs more HSCs completed, they have to rewrite the contract or pay extra on a case-by case-basis. According to AMC/A4, C-17s have to be cycled out of Altus periodically due to the wear that students place on the components, especially the landing gear and wings (Dorsch, 2014). HSCs will be completed at the previous home station prior to cycling into Altus, and then at Altus before cycling to its next duty station (Dorsch, 2014). While Altus is an anomaly, it will be included in the analysis to give leadership an additional data point.

The model used in this research considers trade-offs among personnel, transportation, and facility costs. If personnel and facilities dominated the costs, then economies of scale would lead the model to fewer consolidated facilities. However, if aircraft ferry costs dominated, then the model would lead to more facilities. The factors that RAND used to derive their solution for C-130s were the following: First, they accounted for programmed flying hours and inspection intervals; second they looked at total aircraft inventory and beddown; third, they assumed personnel costs of $65,000 per person-year; fourth they estimated the aircraft shuttle cost at $5,300 per flying hour; and finally, they calculated the facility costs at $2 million per year per inspection dock, amortized.

There are two important notes of interest in the RAND methodology which will play a direct part in my research. First, the transportation costs incurred from shuttling the aircraft assumed that the aircraft were not being used for any training or cargo missions and charged the full cost per flying hour. This is the most conservative assumption since, in reality, at least some of these sorties would include training or cargo, but would be impossible to predict and therefore must be ignored for this research. Second, the

researchers did take into account that some facilities would need to be upgraded or constructed at the selected consolidated facilities, whereas, my research assumes no new capital construction costs.

The RAND report concludes that “consolidating certain wing-level scheduled maintenance tasks and off-equipment component repairs is more effective and efficient than the current system, in which every wing has significant maintenance capabilities to support these activities” (Tripp, McGarvey, Van Roo, Masters, & Sollinger, 2010). Specifically the authors find that consolidating inspections is more efficient because it requires fewer people compared with each wing having its own inspection personnel, and it is more effective because consolidation can speed the flow of aircraft through inspections, making more aircraft available for operational requirements. Larger, consolidated operations could employ up to three-shifts working almost continuously, allowing for quicker inspections. Furthermore, according to the report, “consolidating scheduled inspection and back shop operations not only would provide immediate benefits but also could provide a good basis for integrating stove piped intermediate and depot level processes, thereby creating the opportunity for even greater efficiencies and effectiveness” (Tripp, McGarvey, Van Roo, Masters, & Sollinger, 2010).

## C-5 Consolidation Initiative

The Air Force has investigated ways to change the C-5 isochronal (ISO) inspection process including consolidation of existing aircraft inspection sites, using new inspection site-aircraft assignment selection methods, and adopting new aircraft inspection procedures. Unlike the C-17 HSC regionalization that this paper researches,

the goal of the 2009 C-5 regionalization was not driven by cost or manpower, but rather aircraft availability (AA) rate and mission capable (MC) rate. Although there are some differences between a C-17 HSC and a C-5 ISO, this author will assume that any differences in the inspections themselves or timeframe involved does not affect the overall results of the regionalization.

According to the "C-5 Regional Isochronal Inspection Implementation Plan" signed by Brigadier General Kenneth Merchant, the regionalized ISO (R-ISO) concept was "designed to pool scarce resources, synergize efforts, and streamline and standardize inspection processes to accomplish quality ISO inspections more efficiently, providing greater aircraft availability to the warfighter" (HQ AMC/A4MY, 2009). This plan consolidated the ISO inspections for eight C-5 home stations into three locations: Westover AFB, Martinsburg AFB, and Dover AFB. The Air Force hoped to gain efficiencies "by having the same people perform these inspections for all flying units and by adopting commercial aircraft condition-based inspection strategies" (Johnson, Heiman, Cooper, & Hill, 2010)

Like the C-17 HSC, the C-5 ISO is similar to a mix between a commercial B and C-check and is divided into minor and major inspections. After implementation of the C-5 R-ISO all major ISO inspections were completed at Dover (13 per year), while all minor inspections were completed at Westover and Martinsburg (52 per year combined) (Carter, 2010). It is important to note that there are only 76 C-5 aircraft in the U.S inventory (scheduled to decrease to 52 by FY16, unless modified by the U.S. Congress) compared to 222 C-17s (Dorsch, 2014).

Recently, the C-5 System Program Director contracted with Intergraph Government Solutions (IGS) to “help determine and capture each R-ISO locations’ best practices, shortfalls and recommend transformations/improvements” (Regional Isochronal Site Visit Final Report, 2011). The contractor team visited all three R-ISO locations to determine whether the regionalization was meeting the stated goals.

The team shared numerous best practices in its report and several recommendations for improvement. There are also several notable issues that have surfaced due to the C-5 R-ISO that should be considered prior to any C-17 HSC regionalization. First, insufficient ramp space hinders flexibility at one of the bases. Any potential regionalized base must have enough ramp space for its assigned aircraft, any transient aircraft, as well as dedicated space for aircraft awaiting or under inspection. Second, regionalized inspection locations must have enough warehouse space to accommodate the increased level of parts and supplies for the aircraft. Overflow of parts and the need for temporary storage containers set up outside in the elements is not conducive to efficiency. Third, regionalized locations will most likely need an increase in manpower to handle the extra throughput. The pre-determined manpower goals must be met in order to ensure success (Regional Isochronal Site Visit Final Report, 2011). Despite the needed improvements identified in the report, the C-5 fleet performance, defined by the AA and MC metrics showed positive results after implementation of the R-ISO (Carter, 2010).

**KC-46 Draft Maintenance Concept**

In order to save money and resources, AMC is discussing an enterprise management system for the new KC-46A tanker, which is expected to start coming online in 2015. This proposed system is much broader than the focus of this paper, and would be easier to implement for a new aircraft platform compared to an existing one. However, consolidated maintenance facilities are a recommended piece of the entire enterprise management proposal, and shows that AMC is seriously considering these types of systems.

Specifically, due to the fiscally constrained environment, AMC wants to "pursue a sustainment approach for the KC-46A which maximizes internal efficiencies while also leveraging commercial best practices and reducing sustainment costs where practical" (KC-46A Enterprise Perspective Maintenance and Sustainment Strategy White Paper Draft, 2013). The enterprise would "own" all the aircraft and allocate them to sortie generation locations (SGLs) for mission and training requirements. Maintenance and supply operations would include an Enterprise Management Center (EMC) and an Enterprise Supply Center (ESC). According to the concept, each SGL would possess minimal maintenance capabilities and the EMC would possess all the capabilities contained at an SGL "as well as additional maintenance capabilities required to facilitate scheduled maintenance activities to include more in-depth component replacement, A-check inspections, etc" (KC-46A Enterprise Perspective Maintenance and Sustainment Strategy White Paper Draft, 2013). Most importantly an EMC would not be co-located with every SGL. The paper admits that more study is required to determine personnel

needs and also recommends a thorough examination of existing statutory and regulatory guidance to reveal what changes are required to implement the proposals.

**Chapter Summary**

Both commercial and DOD research indicates that consolidation of maintenance facilities has the potential for both improvements in efficiency and reductions in costs, depending on certain assumptions and implementation. The C-5 R-ISO presents us with several lessons to incorporate into planning and recommendation for a regionalized C-17 HSC. The RAND research provides several assumptions and a baseline for maintenance regionalization. Additionally, we can see that, as the maintenance program for the new KC-46 is developed, there is significant interest to model it similar to a civilian airline maintenance program with enterprise management and consolidated maintenance facilities.

While the literature review certainly indicates that there are many positives to consolidation and/or regionalization, this research will look specifically at the C-17 fleet in the next few sections and recommend whether a similar approach makes sense.

# III. Methodology

## Chapter Overview

Several optimization models may be suitable to solve centralized maintenance location problems, depending on the underlying assumptions. For example, recently, Gopalan (2014) identified centralized maintenance locations for a commercial aircraft fleet based on their existing routes and schedules, with the goal of minimizing the additional total travel distance incurred due to deviations from their preplanned circuits of flight legs (Gopalan, 2014). Most commercial airlines use a similar model to determine ideal maintenance locations. However, such an approach better suits the regularity of commercial aircraft schedules vis-à-vis military airlift, and so this research sets aside their model and develops one that is specific to AMC's needs.

## Implementation of Mixed Integer Linear Programming Model

In this section, we formulate a mixed-integer linear mathematical programming (MILP) model to determine the optimal locations for HSCs for the C-17 fleet in order to minimize costs, in terms of HSC operational costs, flight hour costs, and TDY costs for personnel travelling to an HSC for maintenance. The parameters are defined as follows:

- Network $G(N, A)$ with nodes $N$ and arcs $A$. The nodes denoted by the set $N$ can be indexed over either $i$ or $j$ for our problem, since the set of possible HSC maintenance locations ($j = 1, \dots, n$) is also the current set of C17 bases ($i = 1, \dots, n$). The arcs that connect the nodes are indexed over $(i, j) \in A$.

- $c_j$ = HSC manning cost ($) per C-17. This is computed as the average personnel salary over the four-month HSC cycle at base $j = 1, \dots, n$, divided by the total number of C-17s assigned to the base to provide cost per 120-day cycle per aircraft. (Note: the average salary includes BAH and COLA rates as applicable).
- $d_{ij}$ = Flying hours between C17 base $i$ and HSC base $j$, defined for $i = 1, \dots, n; j = 1, \dots, n$.
- $F$ = Expected cost per flight hour for C-17 ferry. Currently $14,173 per hour.
- $s_i$ = Supply of C17s at base $i$, each of which requires HSC maintenance ($s_i \geq 0$)
- $d_j$ = Capacity to perform HSC maintenance on C17s at base $j$ $\left(d_j \geq 0\right)$ every 120-day cycle, assuming no personnel constraints, and taking into account ramp and hangar space limitations.
- $t_j$ = Cost ($) of sending a C17 crew TDY to base $j$ for HSC maintenance ($i \neq j$). This term is based on (1) the FY2013 per diem rate, (2) the average number of personnel on a C17 crew that would travel to the HSC for maintenance, and (3) the average duration of HSC maintenance including travel days.
- $Q$ = the maximum number of HSCs for a given scenario being examined

Our decision variables within our model represent the choices to utilize bases for HSCs and to assign aircraft to HSC locations. The first decision variable ($y_j$ for $j = 1, \dots, n$) equals 1 if the MILP determines a particular base $j$ should be used as an HSC based on maximum number of HSCs input by user ($Q$); otherwise it equals zero. The second decision variable ($x_{ij}$ for $(i, j) \in A$) is an integer value representing the number of

C-17s at a particular base "$i$" that are serviced by an HSC at base "$j$". Thus the model formulation is written as follows:

$$\begin{aligned}
&\textit{Minimize} \quad && \sum_{i=1}^{n}\sum_{j=1}^{n} c_j x_{ij} + 2F\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij} + \sum_{j=1}^{n} t_j\left(\sum_{i:i\neq j}^{n} x_{ij}\right) \quad (1)\\
&\textit{Subject to}: && \sum_{i=1}^{n} x_{ij} \le d_j,\ \ \forall\ j \in N,\\
& && \sum_{j=1}^{n} x_{ij} = s_i,\ \ \forall\ i \in N,\\
& && \sum_{i=1}^{n} x_{ij} \le My_j,\ \ \ \forall\ j \in N,\\
& && \sum_{j=1}^{n} y_j \le Q,\\
& && y_j \in \{0,1\}\ \forall\ \ i \in N,\\
& && x_{ij} \ge 0 \ \textit{and}\ x_{ij} \in \mathbb{Z}, \forall\ \ (i,j) \in A,
\end{aligned}$$

**Equation 1: Mixed-Integer Linear Programming Model**

In terms of the mathematical programming formulation expressed above, the first equation, also known as the objective function, represents the quantity we wish to minimize for our problem. The three components of the objective function represent, respectively, the C-17 personnel costs for maintenance personnel assigned to conduct HSCs at each base, the flying hour costs to transport C-17s for HSC maintenance, and the C-17 crew TDY-related costs for HSC maintenance when travel is required. The remaining six equations are the constraints for this mathematical programming formulation. The first constraint ensures that we do not assign more C-17s to a base for HSC maintenance than it can support. The second constraint requires that every C-17 at a base is assigned to some base for HSC maintenance. The third constraint is a logical

constraint which requires that if any C-17s are assigned to a base for HSC maintenance, then the corresponding $y$-variable equals 1 (Ragsdale, 2012). The fourth constraint requires that we utilize no more than $Q$ bases for HSCs. (As a part of this study, we examine the best set of solutions for the current $Q$-value, and for reduced $Q$-values as well.) The fifth constraint requires the $y$-values to be binary, and the final constraint requires that the number of C-17s assigned from a based to a particular HSC maintenance facility be non-negative and integer-valued.

## Cost Analysis

The decision to regionalize the C-17 HSC relies heavily on any potential cost savings; therefore, understanding the cost analysis used in this model is vital prior to making any decisions. For the cost analysis, this research eliminates the costs of equipment and equipment support, as generally these are sunk costs that are common to all current C-17 bases. Also eliminated are facilities costs, including costs to heat, cool, and maintain hangar facilities. These costs were outside the scope of this analysis.

Therefore, each HSC base is analyzed based on its personnel costs to operate as a C-17 HSC and the costs to ferry C-17s to that particular base (cost per flight hour plus crew TDY costs). In other words, the only costs associated with operating a C-17 HSC at a base that already has C-17s assigned are the additional personnel costs, assuming no new capital construction costs.

### *Cost to Operate as a HSC base*

In the course of my research, equipment and non-personnel resources required for C-17 HSCs remained relatively constant across all of the bases. Each of the six required

HSCs are designed to be completed without any unusual, specialized equipment that a C-17 base would not already have. Thus, the number of personnel assigned and/or authorized was the main difference between the bases. This research utilized the best available personnel cost data for this analysis by using the number of HSC personnel authorized by PAA, which was provided by AMC at the following ratio (Dorsch, 2014):

**Table 2: Total Authorized Personnel per PAA**

| | Total C-17s | Total Auth'd per PAA | Total Auth'd HSC Pers |
|---|---|---|---|
| McChord | 53 | 2.5 | 133 |
| Travis | 13 | 5.0 | 65 |
| Hickam | 9 | 7.0 | 63 |
| Elmo | 9 | 7.0 | 63 |
| Altus* | 17 | 5.0 | 85 |
| Charleston | 52 | 2.5 | 130 |
| Dover | 13 | 5.0 | 65 |
| McGuire** | 13 | 5.0 | 65 |

*Civilian contract maintenance
**Approx 50% of personnel dual qualified on both C-17 and KC-10

The term "best available" refers to the fact that not all data was available and accounting measures differed between bases. Some bases have differing numbers of actual C-17s assigned versus officially primary assigned aircraft (PAA). For example, McChord has two C-17s assigned to Backup Aircraft Inventory (BAI) status, therefore the HSC personnel ratio may not be exact. Another exception pertains to Altus, which uses civilian maintainence, as discussed in more detail in the previous section. The PAA assigned to Altus do not translate into civilian manning with the same ratio as active duty maintainers, as Altus aircraft maintenance is paid a flat rate for the contracted work and can hire as many or as few personnel as required. However, the model will use an

estimated military personnel cost for Altus for the baseline run since actual MEO costs were not available.

Also, it is important to note that all bases use HSC authorized personnel to augment other maintenance sections when not needed for HSC work. These individuals may be assigned to different sections or flights, and they potentially work on more than one type of aircraft, which compounded the difficulty in determining the baseline number of C-17 HSC personnel. This means that closing an HSC at a particular base would not translate to 100% personnel cost savings. Some of those personnel would have to still be assigned at the original base for other maintenance tasks, which is a limitation of this model.

To calculate personnel costs for bases selected as an HSC for determining the MILP parameters, this research uses the same HSC authorized numbers discussed above and multiplies the number of aircraft assigned by the MILP to complete an HSC at that base by the personnel cost per 120-day cycle per aircraft. Using a typical example of authorized HSC manning, and averaging the base pay, housing allowance (BAH), and cost of living adjustment (COLA, if authorized) for ranks E-2 through E-7 provided an estimate of the average individual personnel cost for one authorized maintainer. This average was cross-checked versus an example manning document for HSC maintainers which included ranks E-2 through E-8 and was almost identical. Once the average individual personnel cost was determined for a given base, it was multiplied by the authorized number of HSC personnel based on PAA to get a total annual personnel cost. Finally that number was divided by 3 months to get the 120-day cycle cost per base and

divided again by the number of assigned C-17s to arrive at the personnel cost per C-17 per 120-day cycle (See Table 3).

## Table 3: Personnel Costs

| | Avg Annual Salary[1] | | Avg Annual BAH[2] | | Avg Annual COLA | | Avg Annual Compensation | | # Auth'd personnel | | Average Cost per 120 day C-17 Cycle | Divided by # C-17s | Personnel cost per PAA per 120 day cycle |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **McGuire** | $72,789.50 | + | $19,944.00 | + | NA | = | $92,733.50 | x | 65 | ÷ 3 | $2,009,225.83 | 13 | $154,555.83 |
| **McChord** | $72,789.50 | + | $15,972.00 | + | NA | = | $88,761.50 | x | 133 | ÷ 3 | $3,920,299.58 | 53 | $73,967.92 |
| **Charleston** | $72,789.50 | + | $15,099.00 | + | NA | = | $87,888.50 | x | 130 | ÷ 3 | $3,808,501.67 | 52 | $73,240.42 |
| **Travis** | $72,789.50 | + | $18,786.00 | + | NA | = | $91,575.50 | x | 65 | ÷ 3 | $1,984,135.83 | 13 | $152,625.83 |
| **Dover** | $72,789.50 | + | $15,783.00 | + | NA | = | $88,572.50 | x | 65 | ÷ 3 | $1,919,070.83 | 13 | $147,620.83 |
| **Altus*** | $72,789.50 | + | $9,972.00 | + | NA | = | $82,761.50 | x | 85 | ÷ 3 | $2,344,909.17 | 17 | $137,935.83 |
| **Elmo** | $72,789.50 | + | $19,644.00 | + | 12000 | = | $104,433.50 | x | 63 | ÷ 3 | $2,193,103.50 | 9 | $243,678.17 |
| **Hickam** | $72,789.50 | + | $29,988.00 | + | 19200 | = | $121,977.50 | x | 63 | ÷ 3 | $2,561,527.50 | 9 | $284,614.17 |

[1] Average Annual Salary based on Average FY13 Military Pay Rates by grade per year. Average only includes grades E-2 through E-7.

[2] Average BAH calculated from FY14 BAH. Average includes only E-2 through E-7 with and without dependants. Although some of these personnel will be assigned to live on base, there is still a cost associated with them, which this research approximates as the average BAH for that location.

*Altus uses civilian contract maintenance, these numbers are based on estimated military personnel cost

### ***Flight Hours and Operating Cost for Ferrying Between Bases***

The second vital piece of the cost analysis is the cost of ferrying aircraft from home station to other bases for HSCs. This flying hour cost for the C-17 is $14,173 according to AMC, which includes fuel, crew, maintenance, and other miscellaneous costs amortized across the fleet per year (Dorsch, 2014). Any time a C-17 is flown from home station to another HSC facility, the research analyzed the cost per flying hour for a direct flight and included this in the cost analysis. This ferry cost was calculated by determining the estimated flight hours between each base using Combat Flight Planning Software (CFPS) in the Portable Flight Planning Software (PFPS) suite of programs developed and distributed to the DOD by Georgia Tech Research Institute. CFPS is the standard mission planning software for the C-17. The model assumed technical order speeds for both the climb and descent portion of the flight and 310 knots or 0.74 Mach for the cruise portion, and used standard Instrument Flight Rules (IFR) routes of flight to each base.

After the estimated hours of flight time were calculated, these were included it in the MILP for each ferry from base-to-base and then multiplied by two, accounting for the round trip. In order to depict the cost associated with the ferry flight, the flight hours are then multiplied by the C-17 cost per flight hour provided by AMC (See Table 4). In certain cases the flight hours or distances exceeded a standard C-17 fuel load or simply was not practical, for example, a flight from Hickam to Charleston for an HSC. So that the MILP would not consider a non-feasible option, these flights were designated as 99 hours in the MILP and not applicable in the table below.

**Table 4: Flight Hour (Ferry) Costs**

Flight time in Hrs

| | Travis | Hickam | Elmo | Altus | Charleston | Dover | McGuire |
|---|---|---|---|---|---|---|---|
| **McChord** | 1.5 | 5.5 | 3 | 3 | 5 | 5 | 5 |
| **Travis** | | 5 | 4.5 | 2.7 | 4.8 | 5.1 | 5.3 |
| **Hickam** | 5 | | 5.7 | 7.3 | NA | NA | NA |
| **Elmo** | 4.5 | 5.7 | | 6 | NA | NA | NA |
| **Altus** | 2.7 | 7.3 | 6 | | 2.5 | 2.8 | 2.8 |
| **Charleston** | 4.8 | NA | NA | 2.5 | | 1.3 | 1.5 |
| **Dover** | 5.1 | NA | NA | 2.8 | 1.3 | | 0.5 |
| **McGuire** | 5.3 | NA | NA | 2.8 | 1.5 | 0.5 | |

### *Crew TDY costs for off station HSC*

Assuming a consolidation of HSC bases, aircrew will have to fly aircraft to these new HSC locations from their current home station. These TDY costs must be accounted for in the overall cost and decision analysis. This model assumes maximum FY 2014 per-diem for a basic C-17 crew of 3 (i.e., 2 pilots, 1 loadmaster) for a worst case consisting of 5 full days (2 travel days on either side of the 3 days estimated for the HSC). Each travel day is calculated at 75% of the max rate per diem and incidentals with lodging cost incurred only on the first travel day. Each of the other days TDY account for full per diem, incidentals, and max lodging rates. The rates were obtained directly from the Defense Travel Management Office rate query web site. If more than one per-diem rate existed due to seasonal variability, the more expensive rate was used. The estimate does not factor in rental vehicles (if authorized) versus government owned vehicles, vehicle fuel, or any other miscellaneous TDY fees or costs. These costs are summarized in Table 5.

**Table 5: Personnel TDY Costs**

| | Max Lodging | M&IE | # of days Full M&IE | # of days 75% M&IE | # Nights Lodging | # of crew | Total Per Diem |
|---|---|---|---|---|---|---|---|
| McChord | $106.00 | $61.00 | 3 | 2 | 4 | 3 | $2,095.50 |
| Travis | $83.00 | $46.00 | 3 | 2 | 4 | 3 | $1,617.00 |
| Hickam | $177.00 | $111.00 | 3 | 2 | 4 | 3 | $3,622.50 |
| Elmendorf | $190.00 | $102.00 | 3 | 2 | 4 | 3 | $3,657.00 |
| Altus | $83.00 | $46.00 | 3 | 2 | 4 | 3 | $1,617.00 |
| Charleston | $173.00 | $56.00 | 3 | 2 | 4 | 3 | $2,832.00 |
| Dover | $103.00 | $46.00 | 3 | 2 | 4 | 3 | $1,857.00 |
| McGuire | $96.00 | $61.00 | 3 | 2 | 4 | 3 | $1,975.50 |

### HSC Capacity per base

The research determines the number of HSCs per 120-day cycle that each base could accommodate, assuming no personnel limitations. Rather than assuming a full 120 usable days per cycle, this research assumes an average of 4 full weeks per month with six usable days per week, equating to 16 weeks and 96 possible days that HSCs could be completed. This allows time for delays, holidays, inclement weather, and other unforeseen issues, if required. The physical limitations of the base, namely, ramp and hangar space, define the potential throughput. Since one of the model assumptions was that each HSC would require a dedicated hangar, bases with more C-17 size-capable hangars could accommodate a greater throughput, assuming they had the ramp space to accommodate the increased traffic.

Charleston and McChord currently average two to three HSCs per week to complete the over 50 required HSCs every 120-day cycle. The other bases all average about 1 per week. The model first considers current capacity ($HSC_{current}$). Every base has at least one or two hangars ($H_{current}$) dedicated almost exclusively to C-17 HSCs. Simply modeling this status quo capacity would allow for some increase in HSC

throughput because one hangar would be used in a non-stop fashion, sometimes referred to as "nose-to-tail" for the 16 weeks per cycle. Another assumption of this model is that a full time dedicated HSC base would complete the inspections in an average of three days during the 96 available days due to an increase in efficiency, allowing for a baseline capacity of 32 inspections, even with just one fully enclosed hangar.

$$HSC_{current} = \frac{H_{current} \times 96\ days}{3\ days/HSC} \tag{2}$$

**Equation 2: Current HSC Capacity**

Next, the research looks to determine maximum HSC capacity assuming no personnel limitations. To calculate this "max surge capacity," ($HSC_{max}$) the research determined the total amount of fully enclosed C-17 capable hangars ($H_{max}$) per base and allowed all to be used "nose-to-tail" over the 96 possible HSC days. This is a fairly unrealistic number since it assumes that every fully enclosed C-17 capable hangar at a particular base would be completely dedicated to conducting HSCs. Since several bases have multiple types of aircraft assigned, and other C-17 repairs also require hangars this should simply be considered a theoretical number used in the model.

$$HSC_{max} = \frac{H_{max} \times 96\ days}{3\ days/HSC} \tag{3}$$

**Equation 3: Maximum HSC Capacity**

Finally, the model proposes a "potential capacity" ($HSC_{pot}$) for all bases with several fully enclosed C-17 capable hangars. This potential capacity adds one more hangar to the current capacity ($H_{pot}$), which is available at every base in the form of a

wash rack, fuel cell, paint barn, spare general hangar or another type of dedicated hangar facility.

$$HSC_{pot} = \frac{H_{pot} \times 96\ days}{3\ days/HSC} \qquad (4)$$

**Equation 4: Potential HSC Capacity**

By dedicating one more hangar to HSC inspections, the base would potentially be giving up capability elsewhere and it is outside the scope of this paper to weigh the costs of losing a dedicated wash rack or fuel cell hangar with the benefits of having increased HSC throughput capacity. However, future research could look at hangar utilization by type and determine if hangar types that were less often used could be consolidated. This “potential capacity” is the most realistic of the regionalized HSC base capacity numbers and will be the primary number that the model is based on for the analysis of this research. See Table 6: Hangar Capacity.

## Table 6: Hangar Capacity

| | C-17s | Usable days per 120 day cycle | Current Hangar Capacity ($H_{current}$) | Current HSC Capacity ($96 * H_{current}$) / 3 days | Potential Capacity ($H_{pot}$) ($H_{current} + 1$) | Potential Thru-put ($96 * H_{pot}$) / 3 days | Max Surge Capacity $H_{max}$ | Max Thru-put ($96 * H_{max}$) / 3 days |
|---|---|---|---|---|---|---|---|---|
| **McGuire** | 13 | 96 | 1 | 32 | 2 | 64 | 5 | 160 |
| **McChord** | 53 | 96 | 2 | 64 | 3 | 96 | 5 | 160 |
| **Charleston** | 52 | 96 | 2 | 64 | 3 | 96 | 7 | 224 |
| **Travis** | 13 | 96 | 1 | 32 | 2 | 64 | 7 | 224 |
| **Dover** | 13 | 96 | 1 | 32 | 2 | 64 | 2 | 64 |
| **Altus** | 17 | 96 | 1 | 32 | 1 | 32 | 1 | 32 |
| **Elmo** | 9 | 96 | 1 | 32 | 2 | 64 | 3 | 96 |
| **Hickam** | 9 | 96 | 1 | 32 | 2 | 64 | 3 | 96 |

**Determining the most cost efficient number of HSCs**

In the MILP formulation, $Q$ is defined as the maximum number of HSC bases. Currently, all eight C-17 active duty bases conduct their own HSCs, so if we set $Q = 8$ in the MILP, and set all base HSC capacities to actual number of assigned aircraft, the model will provide us the current baseline cost. In other words, all bases will be assigned an HSC, no aircraft will ferry to another base, and no crew TDY costs will occur. However, if $Q$ is set less than 8, and base HSC capacities are set as described previously, then the MILP will minimize costs while determining the bases that should be defined as HSC locations. Due to the high costs of ferrying C-17s, the formulation has a strong bias towards assigning locations with a high number of C-17s an HSC. This also works in favor of economies of scale, since the bases with the most number of assigned C-17s have the lowest number of authorized personnel per PAA, significantly reducing the cost to operate that particular HSC.

**Chapter Summary**

This chapter discussed the methodology behind the cost minimization MILP model used in this research. First the objective function and the component functions for the MILP were introduced, including its constraints and variables. Next, the reader was presented with a detailed explanation of the numbers behind the cost analysis including the cost to operate a base as an HSC, C-17 flight hour costs for ferry calculations, crew TDY costs, and the three types of HSC base capacity. These three capacities: current, potential, and maximum are vital to understanding  the analysis in the next section. Finally, $Q$ was presented to show the reader how the analysis will be conducted based on

the number of “allowed” HSC bases and finally how the cost minimization will take place.

# IV. Analysis and Results

## Chapter Overview

The previous chapter described how the data was collected and modeled. This chapter will focus on the results of this research as it applies to the questions posed in Chapter I. Each section below will analyze the results of the data and modeling presented in Chapter III and present an overview of the final results.

## Baseline

As previously established, currently every active duty C-17 base completes their own HSCs. Based on my research and the model assumptions, the current total 120-day HSC cycle cost for all eight active duty bases to maintain their own HSC is $20,740,774. This is the total baseline personnel cost to operate the HSCs, and equates to approximately $62,222,300 per year (see Figure 1:  Baseline). Assuming no changes are made to the C-17 HSC program, this is the approximate baseline cost that the maintenance incurs and is the cost to which all of the modeling will be compared.

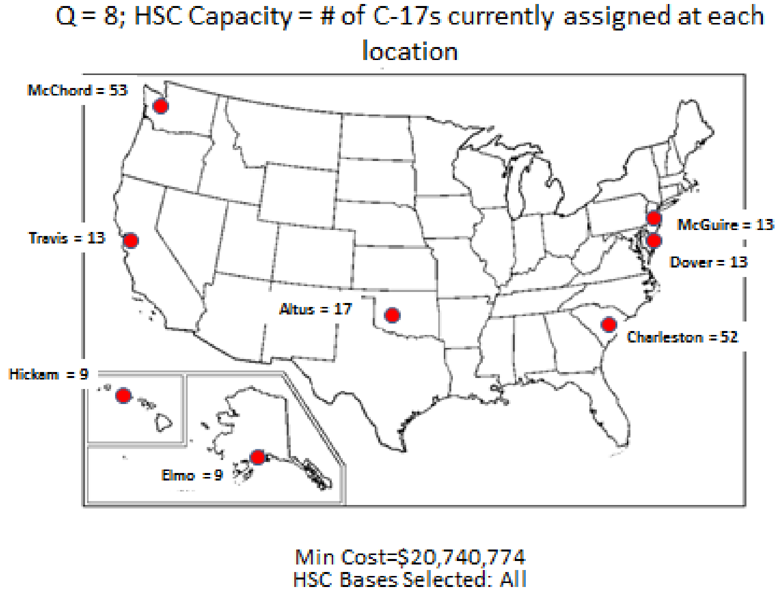


**Figure 1: Baseline Cost Analysis**

## Model Development

Since the current HSC cost baseline has been established, the first model iteration has been run with each base's capacity set to $HSC_{max}$. In other words, given the established costs to operate an HSC, and the ability to flow C-17s to any or all of the eight bases in any number up to the hypothetical maximum described in the previous chapter, the model will minimize the overall costs by taking into account flying hour and TDY costs associated to aircraft that are assigned an HSC at a base other than home station. For this iteration, Q = 8 and HSC capacity is set at $HSC_{max}$ for each base. This model shows that, assuming maximum capacity, it is less expensive to assign 84 C-17s to McChord, 78 to Charleston, and the remaining 17 to Altus for HSCs, eliminating the HSC costs at Hickam, Elmendorf, Travis, McGuire, and Dover entirely. This maximizes economies of scale allowing for the fewest number of personnel per aircraft. The 120-day

cycle cost is $18,162,570 and the approximate annual cost is $54,487,700, a 12.4% savings from the baseline (see Figure 2).

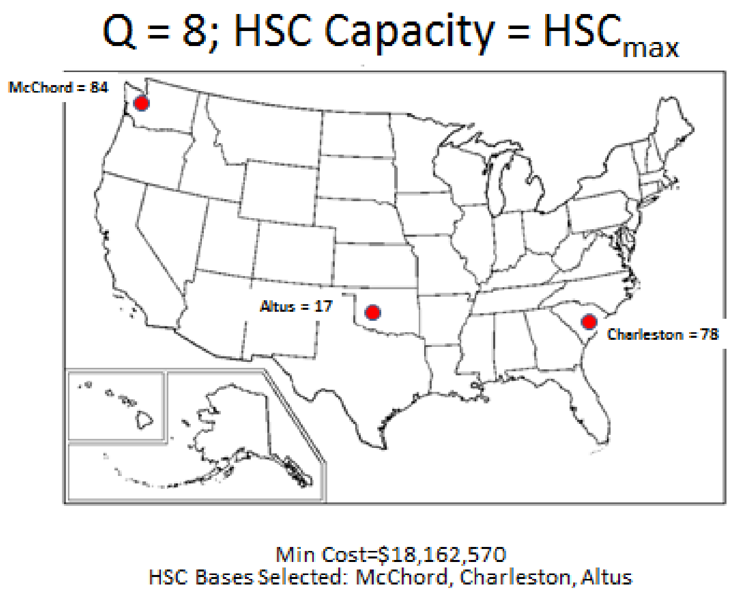


**Figure 2: Iteration 1, Q = 8, HSC Capacity = $HSC_{max}$**

Of course, this maximum capacity is not entirely realistic and is modeled to set an upper limit and show how the model is weighing the constraints to determine the minimum costs associated with the C-17 HSC. The next model is run with Q = 8 and HSC capacity at current capacity, $HSC_{current}$ to show potential cost savings using "nose to tail" operations and only using the one or two hangars currently dedicated to C-17 HSCs at each existing bases. The model minimizes costs by also consolidating HSCs at McChord, Charleston, and Altus, maxing out capacity at both bases on both of the coasts. However, the model has to leave one C-17 at McGuire due to lack of capacity at Charleston, and similarly has to leave seven aircraft at Hickam due to lack of capacity at

McChord. This, of course, is a limitation of the model due to the way it calculates HSC costs, and AMC would not likely leave an HSC capability at a base for just a small number of aircraft. Nevertheless, the minimized cost in this example is $19,460,714. However, if capacity is increased by one aircraft at Charleston, this allows McGuire's HSC to close, rather than remain open for one aircraft. Also, capacity is decreased at Hickam to zero; allowing the model to close that HSC yields the results shown in Figure 3.

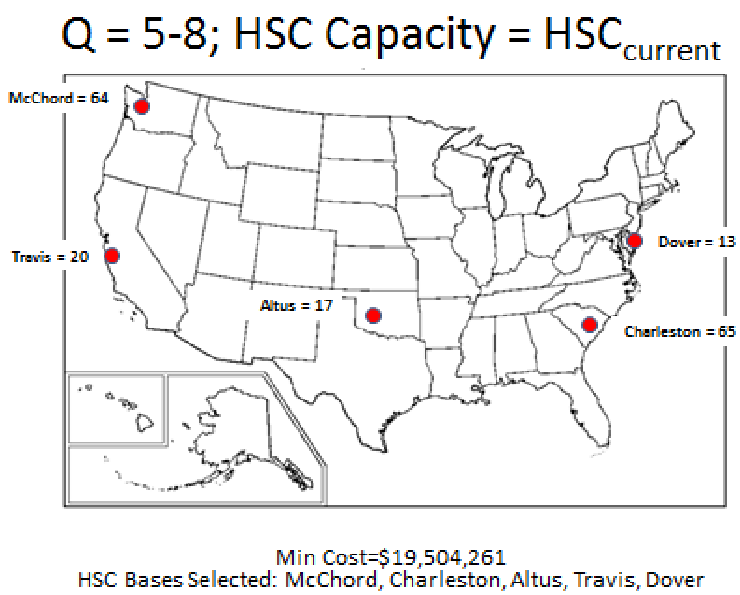


**Figure 3: Iteration 2, Q = 5-8, HSC Capacity = $\mathbf{HSC_{current}}$**

These slightly modified results are a much better estimate of costs. The model is allowed to fully close three HSC locations, and the results show a total cost of $19,504,261 per 120-day cycle or approximately $58,512,800 per year, a 6% savings

from the baseline. All of McGuire's C-17s would complete HSCs at Charleston and all of Elmendorf's and Hickam's C-17s would complete HSCs at McChord and Travis.

So far each of the models has left Q = 8, allowing the model to potentially use all the current HSC bases. However, if we decrease the allowed number of Q bases to seven, six, or five, the model still gives the same results as described above. If we continue to decrease Q further, cost increase as aircraft are forced to flow to Altus at Q = 4, and below Q = 4, maximum capacity is reached at each base and the model does not have a solution using $HSC_{current}$.

Therefore, the next step is to set each base's capacity to $HSC_{pot}$. This will allow increased capacity by one hangar at each base, and allow the model to consider a Q less than four. In this itereation, the model results are identical to $HSC_{max}$ with Q constrained anywhere from three to eight. These results are shown in Figure 4, with McChord, Altus, and Charleston selected and a minimized cost of $18,162,570, a 12.4% savings from the baseline. If we set Q = 2, then Altus HSC closes, those jets flow to Charleston and the cost is $18,315,596, slightly more expensive then Q = 3, or a 11.7% savings from the baseline (Figure 5). Finally, Q = 1 is not possible, due to capacity issues.

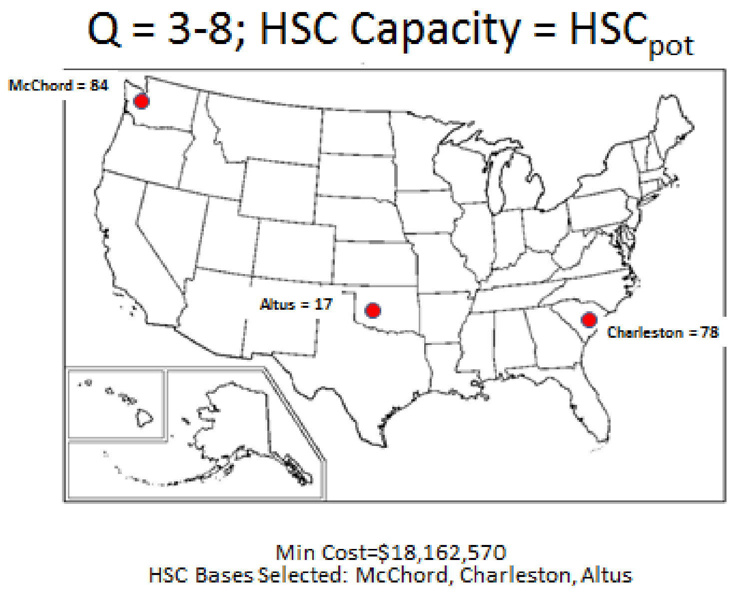


**Figure 4: Iteration 3, Q = 3-8, HSC Capacity = HSC$_{pot}$**

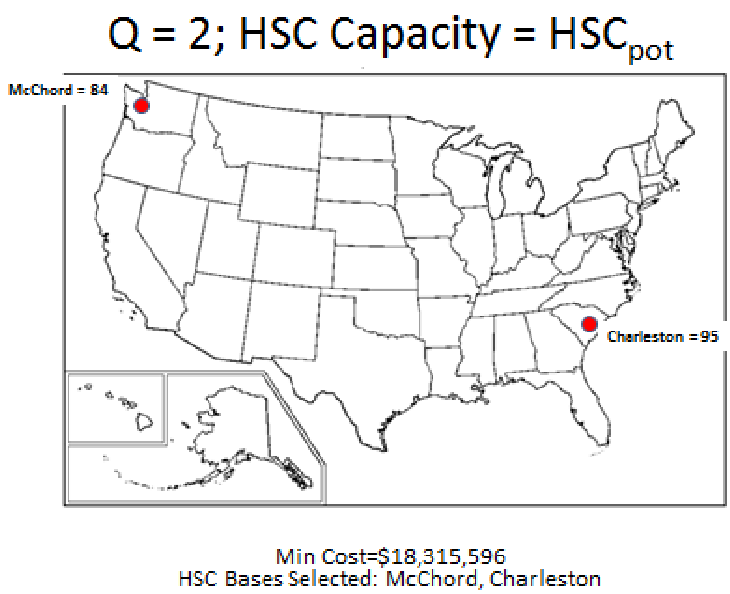


**Figure 5: Iteration 4, Q = 2, HSC Capacity = HSC$_{pot}$**

So far, we have assumed that each base has an equal chance of operating as an HSC or not operating as an HSC dependent on personnel costs. However, this assumption may not reflect the reality of the situation. As previously discussed, Altus has an all-civilian maintenance MEO team which completes a set number of HSCs. Although the number of HSCs completed by Altus could be increased, according to AMC/A4, the maintenance costs there would increase if the number of aircraft inspections increased (not accounted for in this model). Furthermore, because Altus falls under AETC and those jets are effectively removed from the operational system during their time at Altus, it is likely that Altus will be considered its own entity and continue to complete HSCs only on the seventeen aircraft at that base. Similarly, Elmendorf and Hickam are PACAF bases and would potentially be unwilling to participate in any AMC-led consolidation. If we assume that both PACAF bases and Altus maintain their status quo by setting their constraints to equal the number of C-17s assigned to them in the model we can provide AMC-only HSC regionalization results. In this iteration, Q = 8 and capacity is set to $HSC_{pot}$ for each AMC base and actual number of C-17s assigned for Elmendorf, Hickam, and Altus. See Figure 6.

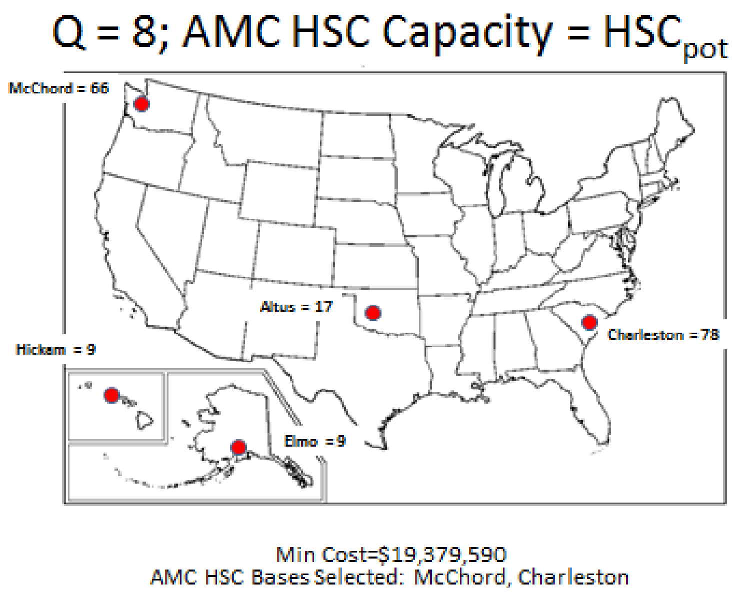


**Figure 6: Iteration 5, Q = 8, AMC HSC Capacity = HSC$_{pot}$**

This iteration provides us a 6.6% savings from the baseline with a minimized HSC cost of $19,379,590, or $58,138,800 annually, by closing HSCs at McGuire, Dover, and Travis, and having those C-17s flow to McChord and Charleston for HSC maintenance, while still leaving Altus, Elmendorf, and Hickam open per the discussion above.

The following table summarizes the results from the modeling above.

**Table 7: Summary of Modeling Results**

| | Q | # of HSC Bases | Capacity | 120 day cycle cost | Annual Cost | $ Savings from Baseline Annual Cost | % Savings |
|---|---|---|---|---|---|---|---|
| Baseline | 8 | 8 | Actual | $20,740,774 | $62,222,322 | **$0** | **0.0%** |
| Iteration 1 | 8 | 3 | HSC$_{max}$ | $18,162,570 | $54,487,710 | **$7,734,612** | **12.4%** |
| Iteration 2 | 5-8 | 5 | HSC$_{current}$ | $19,504,261 | $58,512,783 | **$3,709,539** | **6.0%** |
| Iteration 3 | 3-8 | 3 | HSC$_{pot}$ | $18,162,570 | $54,487,710 | **$7,734,612** | **12.4%** |
| Iteration 4 | 2 | 2 | HSC$_{pot}$ | $18,315,596 | $54,946,788 | **$7,275,534** | **11.7%** |
| Iteration 5 | 8 | 5 | HSC$_{pot}$ | $19,379,590 | $58,138,770 | **$4,083,552** | **6.6%** |

## Analysis

There are several reasons to consider C-17 HSC regionalization, including taking advantage of economies of scale to increase efficiency, and also to create more standardization at HSC bases. Because the manpower authorized for HSCs to a base decreases commensurate with the number of aircraft assigned, the biggest cost savings come from regionalizing C-17 HSC to a number greater than 50 per base, dropping the authorized manpower to 2.5 per aircraft. The model shows that there is some savings possible via HSC consolidation; however, it is important to remember that the monetary savings modeled above will be diminished by the fact that closing an HSC at any given base does not equate to eliminating all of the HSC maintenance personnel at that base. Although the maintenance personnel numbers would decrease without an HSC requirement, there would likely be an increased manpower authorization in other areas to make up for the lost personnel. Additionally, at a base like McGuire, where many HSC personnel are dual-qualified on both the C-17 and KC-10, the savings would be significantly smaller.

## Analysis Overview

The baseline cost analysis shows the estimated current HSC costs of all active duty C-17 bases. This cost is estimated based on the average HSC personnel cost at each base. The model assumes standardized cost comparisons and varies HSC capacities at each base to produce estimated overall costs from various regionalization scenarios. Furthermore, the model considers the effect of non-AMC bases wishing to maintain their own HSCs. For every HSC that is eliminated, the DOD will incur flying hour costs,

TDY costs, and unknown costs associated with changing the distribution of maintenance personnel across the bases. However, there will also be cost savings by eliminating maintenance positions at non-HSC selected bases. In the following chapter we will compare the various results of the model, consider other potential solutions, look at areas of future study, and finally make a recommendation to AMC leadership regarding the merits of C-17 HSC regionalization.

# V. Conclusions and Recommendations

## Conclusions

Based on this research, there are cost savings possible by regionalizing some active duty C-17 HSC locations. This research also shows that regionalization may increase the overall efficiency of the process, as it would speed the flow of aircraft scheduled for inspection, and reduce the average time to approximately three days at the given facility, increasing the aggregate number of aircraft available for operational requirements. Furthermore, regionalization will enable more efficiency in HSC operations since fewer maintenance personnel per C-17 would be required. As demonstrated in the RAND report and the C-5 regionalization initiative, consolidated facilities are likely to be more efficient due to labor economies of scale allowing larger maintenance operations to use personnel more efficiently. Regionalization minimizes minimum-crew size effects, allowing the smallest AMC defined ratio of personnel to aircraft. However, there are also some negatives to C-17 HSC regionalization, including some loss of maintenance flexibility, and possible impact to combat operations. Thus, despite the savings potential, there are a few limitations worth mentioning in the next section before providing a final recommendation.

Chapter one outlined four specific questions for this research. As described above, the results of the data analysis indicate:

1. The MILP analysis shows that a regionalized C-17 HSC program could provide the USAF with cost savings and increased efficiencies. The ideal number of bases is three: McChord, Charleston, and Altus, assuming PACAF agrees to regionalization, providing up to a $7.7M savings per year. If PACAF does not agree to regionalization, the ideal number of bases is five: McChord, Charleston, Altus, Hickam, and Elmendorf, providing up to a $4M savings per year.

2. There are several similar regionalization programs in both the commercial and military maintenance arenas. Furthermore, RAND completed a similar study on C-130 maintenance consolidation that also found savings.

3. It is possible to increase HSC capacity at a given base using existing fully enclosed C-17 capable hangars in a more efficient “nose-to-tail” schedule by dedicating manpower solely to HSC work and augmenting with other maintainers as required. Furthermore, if each HSC base increased its hangar capacity by repurposing one more fully enclosed C-17 hangar, which is a possibility at each base, capacity would increase even further.

4. Since this research shows that cost savings exist, HSC regionalization appears to be a plausible idea. However, there are some caveats and areas of further study required.

**Limitations**

This research project is necessarily limited in scope. The research focuses on the costs associated with each base having fully authorized manpower to conduct their own HSCs for all of their assigned C-17s. As previously discussed, this research defined the costs of maintaining an HSC as the personnel costs to maintain HSC authorized manpower; however, there may be other costs including facility and equipment maintenance costs that could not be accurately defined for the model. This research assumes these as sunk costs that will likely still be incurred to a certain extent whether the base retains an HSC or not. Therefore, this research has attempted to fully qualify the potential savings of regionalization but actual real-world results may be different.

This research also only studies active duty C-17 locations. There are a total of 15 bases currently assigned C-17s and this research only studies eight of them. This was an intentional limitation, due to the political ramifications of moving or reducing authorized personnel at Guard and Reserve bases. The intent was to research any cost effectiveness

of regionalization for just the active duty, purporting an easier path to implementation and proof of concept before expanding to the Guard and Reserve, if successful.

This project does not account for diminished combat capability if C-17 HSC regionalization occurs. Potentially, if HSC capable personnel are reduced, there may not be enough maintainers to forward deploy in a contingency situation.

Lastly, this project offers cost-minimization recommendations based on moving HSC locations; however, it does not take into account any costs not explicitly stated. For example, any PCS costs associated with moving personnel or costs associated with eliminating or reducing personnel. Furthermore, each base studied has a comparatively small number of civilian and reservist maintainers that would not be as easy to regionalize or eliminate compared to active duty maintainers.

**Recommendations**

Based on the findings of this research, AMC should consider regionalization of the C-17 HSC. Specifically, there are two recommendations that make sense, dependent upon whether PACAF will agree to regionalize or not.

First, a full regionalization using McChord, Charleston, and Altus will save the Air Force the maximum amount of money and allow for the greatest economies of scale. In order to regionalize to this extent, all of the Travis, Elmendorf, and Hickam C-17s would be scheduled for HSCs at McChord, in addition to their own 53 aircraft. McChord has two fully enclosed C-17 capable hangars that are already used primarily for HSCs and another one that is considered general purpose and easily repurposed for a total of three dedicated HSC hangars. McChord would be charged with completing 84 HSCs in a

total of 96 usable days within the 120-day cycle. With the increase in HSCs, they would need an increase in manpower commensurate with the ratio of 2.5 per HSC, or 210. Many of these 210 personnel would be working full time on HSCs, but would still be available to work in other maintenance areas as is the current practice. Similarly, Charleston would be responsible for all HSCs for McGuire and Dover, in addition to their own aircraft. Charleston currently uses a large enclosed hangar that can contain two C-17s for HSCs, and also has a general purpose hanger that could be repurposed. 78 aircraft would have HSCs scheduled at Charleston, requiring 195 HSC personnel. Altus would continue to conduct HSCs on their own aircraft and there would be no change in cost due to their civilian MEO maintainers. This research shows that this regionalization plan may save the Air Force up to $7.7 million per year, a 12.4% savings from the current baseline costs, with the caveats already identified.

The second course of action should be considered if PACAF does not want to regionalize. This plan would allow Hickam, Elmendorf, and Altus to all continue HSCs on their own aircraft, while sending Travis aircraft to McChord, and McGuire and Dover aircraft to Charleston. This would allow for some economies of scale and save an estimated $4 million per year, or 6.6% savings, with the caveats already identified.

**Recommendations for Future Research**

It is often difficult to compare military aviation to commercial endeavors. The Air Force does not fly C-17 cargo aircraft to make a profit, and the variety and of missions that are flown and often the last-minute nature of the taskings make it hard to plan like a commercial company. Throughout this research, one area of further research kept

resurfacing—the enterprise management of the C-17 fleet. AMC should continue researching removal of tail flashes from each aircraft, letting them flow through the system where required based on anticipated demand and scheduled missions. If maintenance consolidation is going to truly be efficient, the ferry between bases should be eliminated. Enterprise management would allow aircraft to be scheduled for maintenance months in advance, and then assigned to missions that would bring them directly to the maintenance facility, or at least close, minimizing ferry flight time. While this system would likely have growing pains at first, the efficiencies may outweigh the initial problems.

Prior to any implementation, further study should be conducted on ramp space, which has been demonstrated to hinder C-5 regional operations. At a minimum, insufficient ramp space may hinder flexibility and may prevent HSCs from being conducted on time. Although this research showed that ramp space would likely be sufficient at the bases studied due to advanced scheduling, future basing requirements and/or new or additional aircraft may change this result.

A final area for future research includes HSC base proximity to parts supply locations to minimize necessary warehouse space. An increased number of HSCs conducted at a given base will also increase the number of required parts and material on hand, and may prove unwieldy for some bases existing warehousing options. If there is not sufficient warehouse space, regionalization may not prove as effective.

**Summary**

With the effects of sequestration and potential budget cuts still effecting military readiness, any potential to save money and create efficiencies should be closely examined. This project and research the feasibility of regionalization of the C-17 Home Station Check in order to do both. The research finds first that both commercial and other military examples have shown that regionalization of aircraft maintenance does maximize economies of scale and creates the atmosphere for more efficient inspections. Second, the research finds after studying just active duty C-17 bases that several million dollars per year could be saved with a regionalization plan. This research used a mixed-integer linear programming model to determine the potential cost savings. This model can be easily modified for new assumptions, information, or a desire to look at different options.

As budgets decrease throughout the DOD, this research provides a tool for AMC and DOD leadership to assess whether HSC regionalization is an effort worth pursuing in order to increase efficiency and save money.

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14. ABSTRACT
The Department of Defense is currently dealing with the effects of sequestration and facing an uncertain budgetary future. Senior leaders face tough challenges in deciding where cuts should be made to maximize savings to preserve programs and readiness. Within this environment, the United States Air Force must seize opportunities to find cost savings and efficiency, without decreasing mission effectiveness. This research studies the C-17A Home Station Check, a mandatory maintenance requirement for every C-17 in the USAF fleet, and uses a cost minimization methodology to systematically identify potential regionalization or consolidation options. This study identifies and quantifies the major costs associated with conducting C-17 HSCs, and it examines regionalization options using a mathematical programming model to minimize the total cyclical cost of operations. Based on the analysis, several options to consolidate maintenance on fewer facilities are recommended for consideration that can save from 6.6% up to 12.4% over current C-17 HSC operations.

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